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National Workshop on -

"Recent Advances in Characterization of Aerospace Materials through Impact Testing (RACAMIT-2013)"

Dept. of Aerospace Engg. MIT , Chennai during 23/24- 03 /2013.

"Current product development technologies for polymer matrix composite materials"

Invited talk by

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“Current product development technologies for polymer matrix composite materials”

Dedicated to my beloved teachers

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ROUTE MAP

- INTRODUCTION
- CLASSIFICATION OF COMPOSITES
- COMPOSITE PRODUCT DEVELOPMENT TECHNIQUES
- MANUFACTURING OF PMC- COMPARISON
- OUT OF AUTOCLAVE TECHNOLOGIES
- APPLICATION OF POLYMER MATRIX COMPOSITES IN AIRCRAFT STRUCTURES
- CONCLUDING REMARKS
- REFERENCES
- ACKNOWLEDGEMENTS

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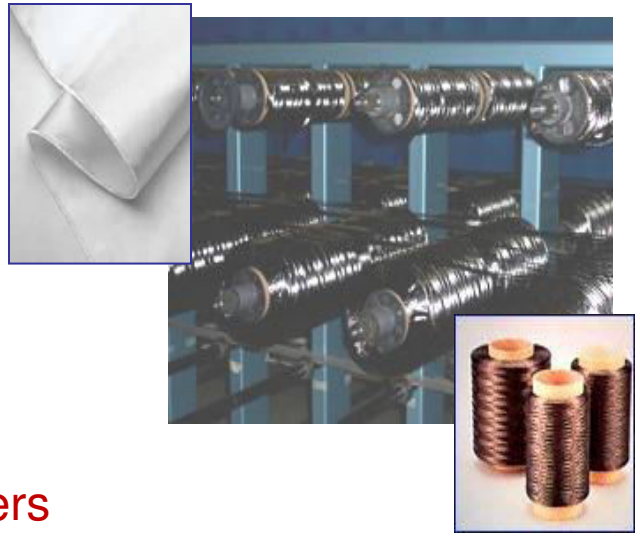
INTRODUCTION TO COMPOSITE MATERIALS

Composites materials are multi-phase materials, where the interaction of the two phases gives overall mechanical and physical properties of an efficient nature. The combination of fiberous reinforcement in a matrix is the most common form of composites.

Eg: Carbon Fiber Rein forced plastic (CFRP)
Glass Fiber Rein forced plastic (GFRP)



Composite = Fiber + Matrix

Fiber → Reinforcing material

Matrix → Binding Material (Hold fibers together)

Eg: Fibers

- Carbon
- Glass
- Boron
- Aramid

Eg: for Matrix

- Epoxy
- Phenotics
- Vinylester
- Polyester

INTRODUCTION TO COMPOSITE MATERIALS

The role of Matrix in a composite :

- It gives shape
- It makes individual fibers of the reinforcement act together
- It protects the reinforcement from the environment
- It provides the transverse strength and stiffness to laminated composites

The role of Reinforcement :

- Provide strength & stiffness
- Controls the thermal expansion co-efficient
- Provides directional properties

Advantages of Fiber Reinforced composites:

- High specific strength and specific stiffness
- The multiplicity of the fibers makes a composite material highly redundant
- Before curing these materials are soft & flexible, as a result it is very easy to produce complex contoured parts
- These materials are ideally suited for repairs because the patch can be made in-situ (Cure-in-place repair).

TYPES OF COMPOSITES

There are several different types of composites used today. The most common are:

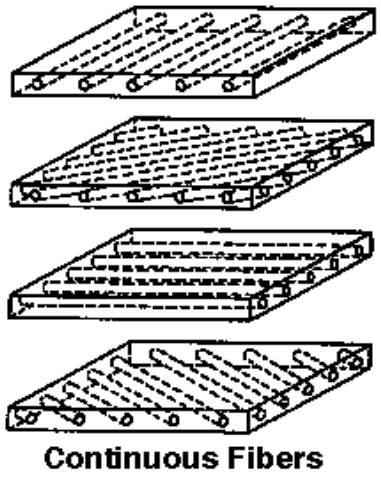
- Fiber reinforced composites
- Particulate reinforced composites

These types of composites cover a range of different material combinations.

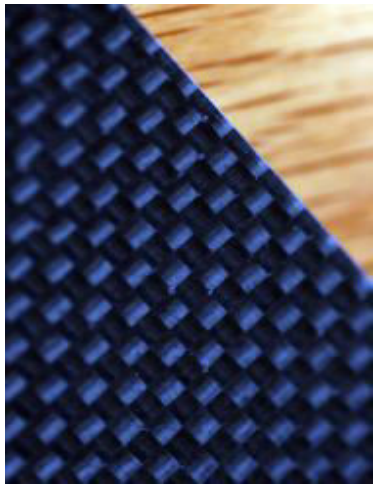
The most common type is **polymer matrix composites**, however,

metal matrix composites, and **ceramic matrix composites** are also common,

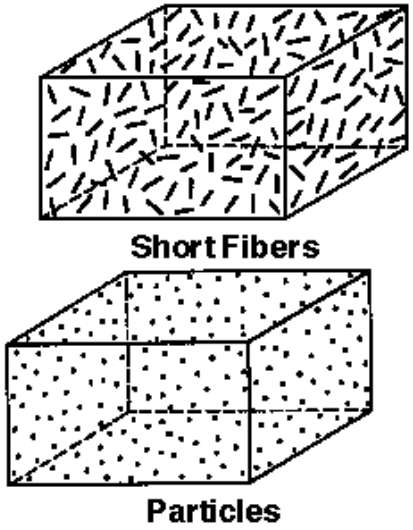
as are **natural composites such as wood.**



Fiber reinforced composites



Carbon fiber reinforced



Particulate reinforced composites,

Concrete

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MANUFACTURING PROCESS FOR POLYMER MATRIX COMPOSITES

I-OPEN MOULDING PROCESS

- ✓ 1.Hand Lay Up
- ✓ 2.Spray Lay Up
- 3.Vaccume Bag Moulding
- 4.Auto clave Moulding

II-CLOSE MOULDING PROCESS

- ✓ 1.Resin Injection Moulding (RIM)
- ✓ 2.Sheet Moulding Compound
- 3.Bulk Moulding Compound (BMC)

III-PROCESS FOR CONTINUOUS FIBRE

- ✓ 1.Filament winding
- ✓ 2.Pultrusion
- 3.Thermal forming
- 4.Prepreg Manufacture.

IV-PROCESS FOR HOLLOW SHAPE

- ✓ 1.Blow Moulding
- 2.Centrifugal Moulding

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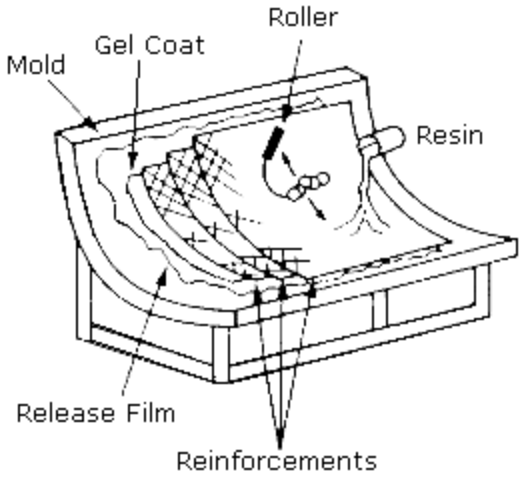
1.OPEN MOULDING PROCESS

HAND LAY-UP PROCESS

- One of the oldest ,cheapest method used for composite fabrication
- This process is common for making components like Ducts, tanks and building doors, roofing panels.

PROCESS:

- Prior to the lay-up process, the mould surface have to be coated with a release agent. (Wax Release)
- The impregnated layers (Cut Layers) are placed on to the mould.



HAND LAY-UP PROCESS

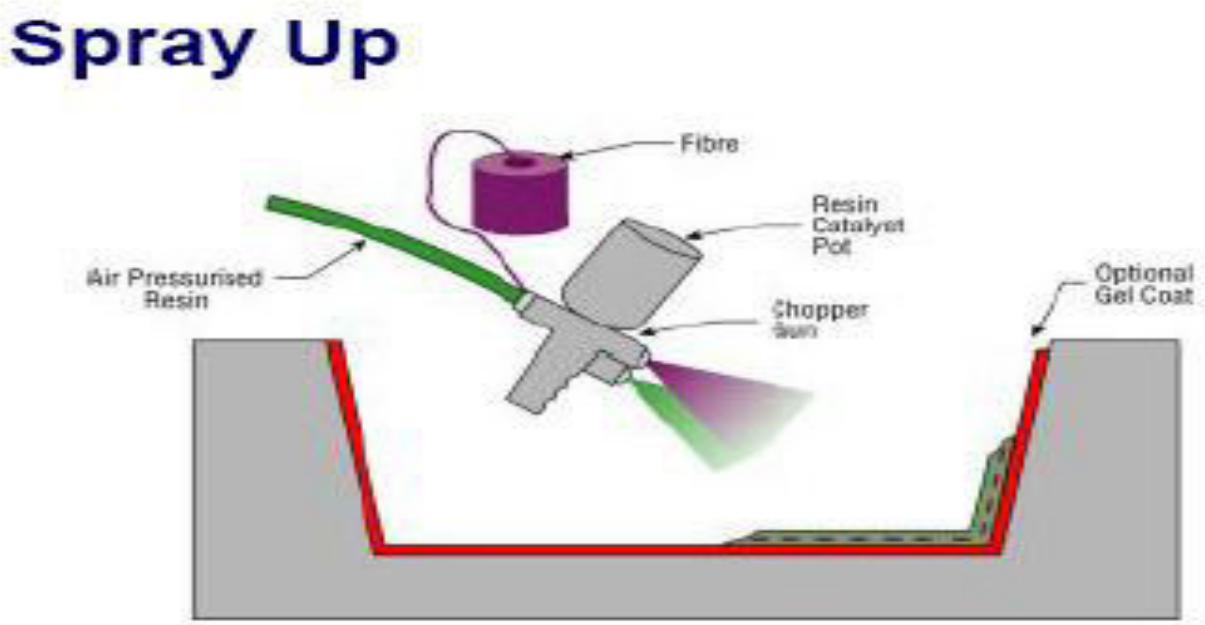
- This process is repeated till the necessary thickness of component is obtained.
- After the last layer, the laminate (part) can be cured at room temperature.
- Then, de-molded and painted the component.
- This process sometimes called as 'wet to wet' as each layer is laid on to the previous layer before it has hardened.

APPLICATIONS:

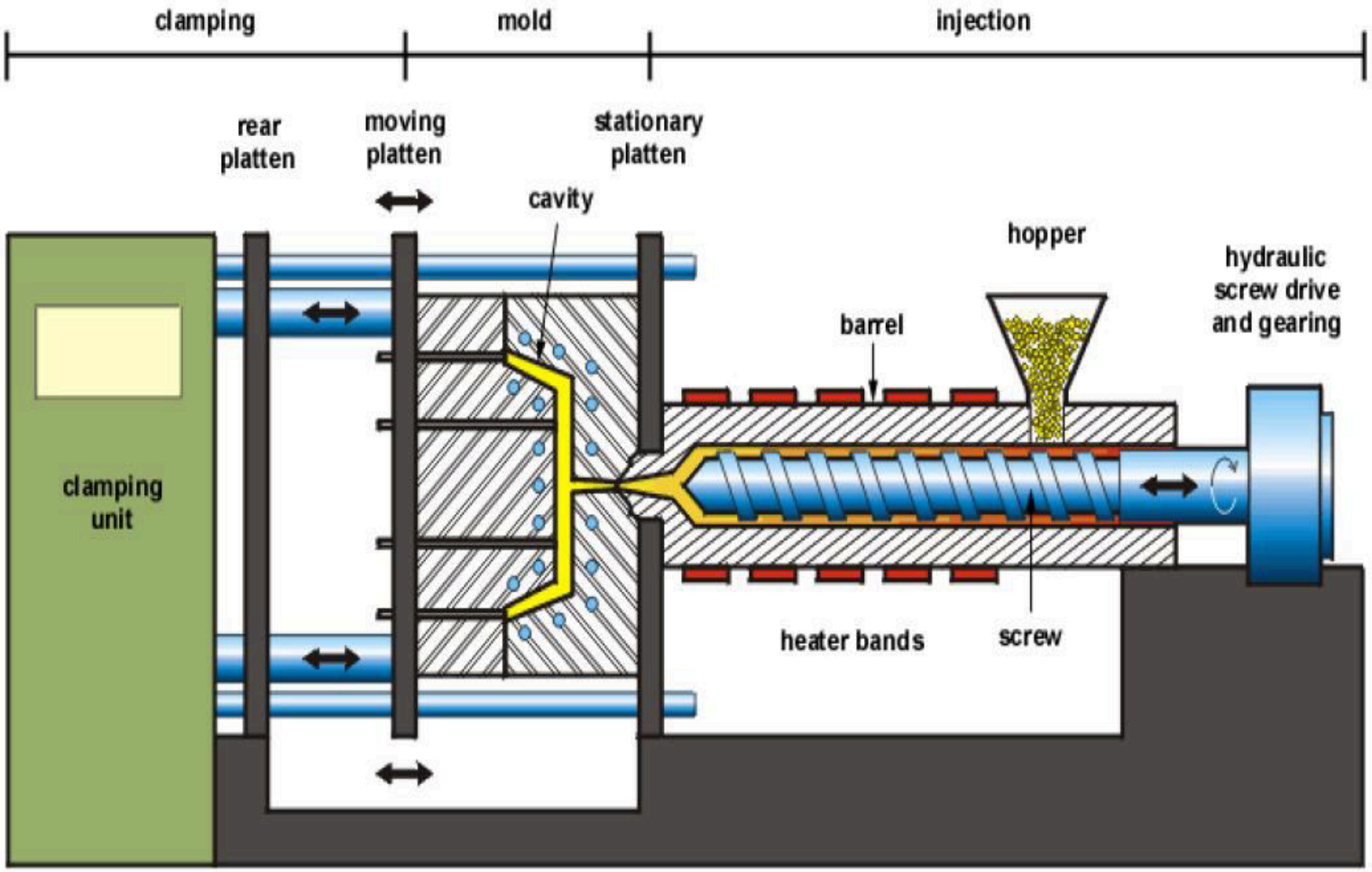
SPRAY LAY-UP PROCESS

PROCESS:

- Moulds are cleaned and spared with gel coat.
- The spray gun simultaneously sprays resin & chopped length fibres on to the mould.
- Rollers are used to compact and removal of air bubbles.
- Then cure at room temperature or at higher temperature in an oven.



2.CLOSED MOULDING PROCESS



Schematic of thermoplastic injection molding machine

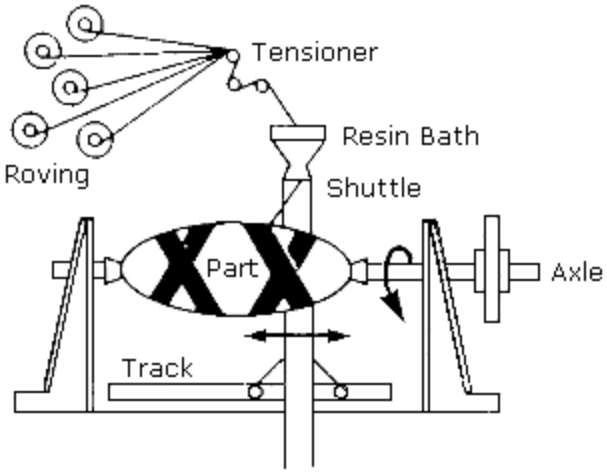
3.PROCESS FOR CONTINUOUS FIBER

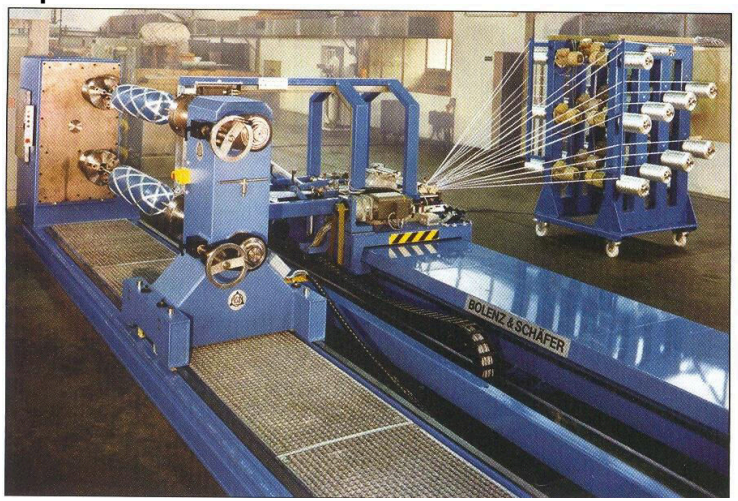
FILAMENT WINDING

- Pipes, Cylinders and Tubes are generally manufactured by this method.
- To produce high performance hollow symmetrical products. (usually cylindrical in nature)
- Very high strength to weight ratios can be obtained.

PROCESS:

- The mandrill is coated with a release agent.
- If the pre-pregs are used they can be directly wound on the mandrills.
- A wide range of winding angles are possible.





FILAMENT WINDING

- So, The reinforcement to be placed ,depends on our strength requirement.

  Axially – To provide bending strength.

  Circumferentially –to resist burst pressure and improve buckling stiffness.

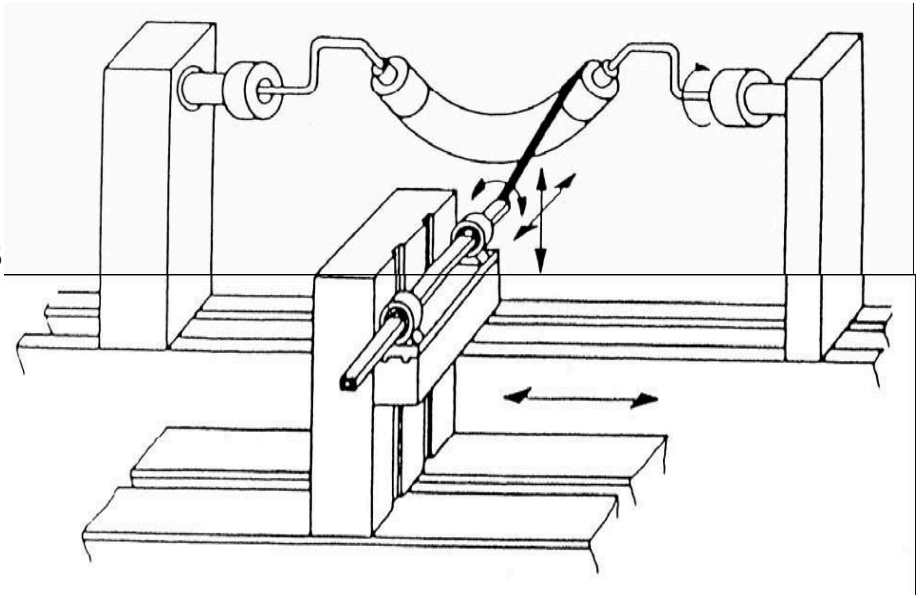
  Cross wise – to enhance tensional strength & stiffness.

- After cure, the mandrill can be easily removed (wax mandrill ,two compound resin systems are used to make the mandrill)

APPLICATIONS:-

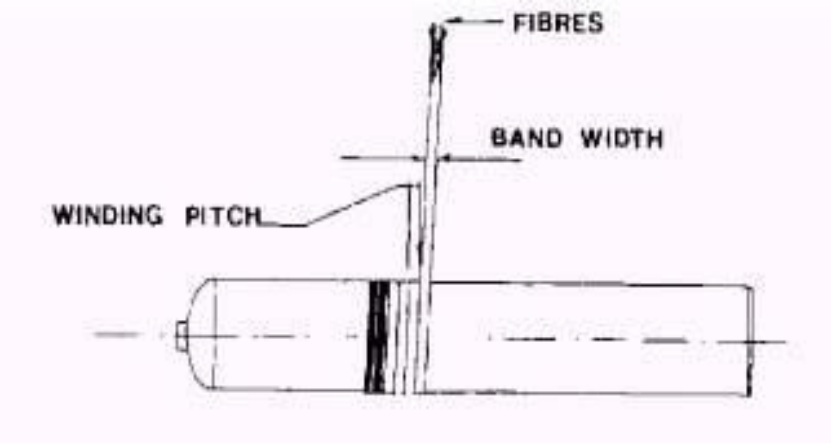
- Very large structure like Water/ Chemical tanks can be made.
- Many types of pressure vessels
- Rocket motors also can be produced

Best suited for Axi-symmetric sections (Tubes, cyrs,etc)

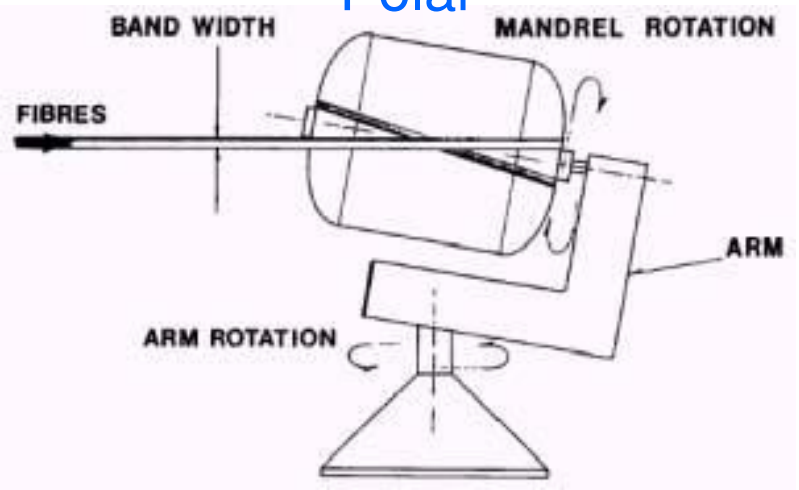


Filament winding - winding patterns

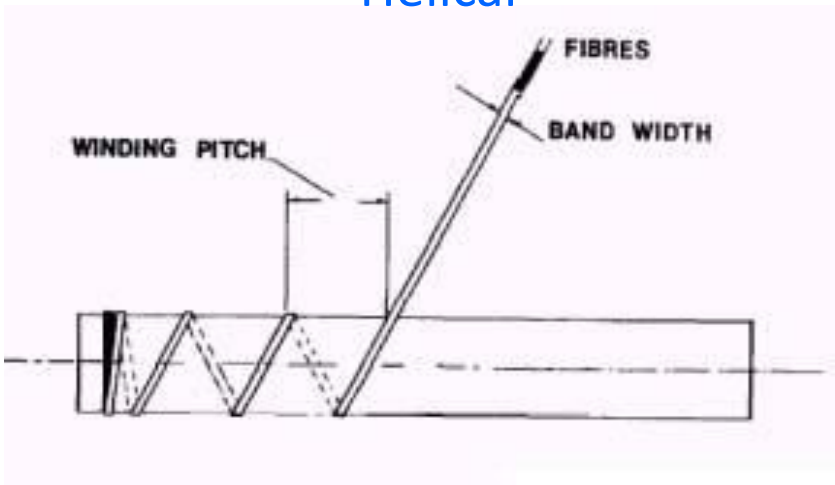
Hoop



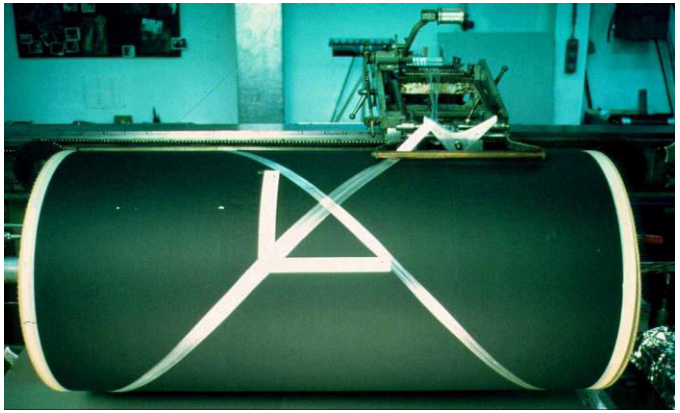
Polar

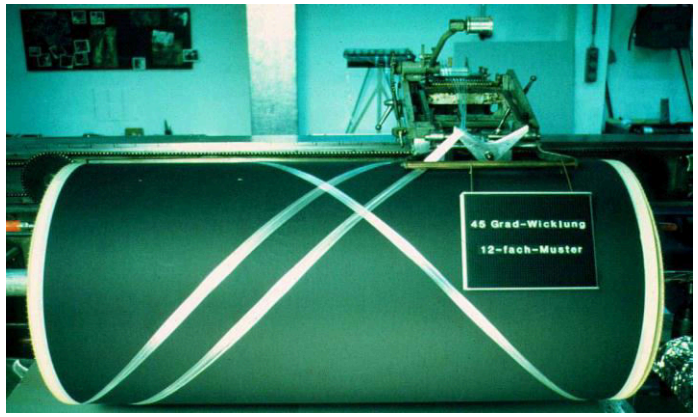


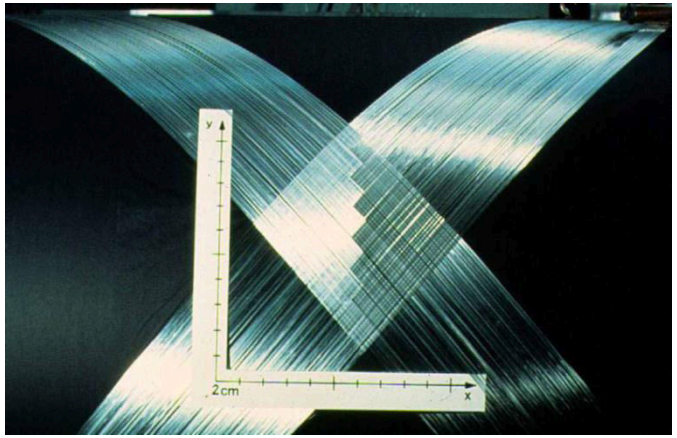
Helical

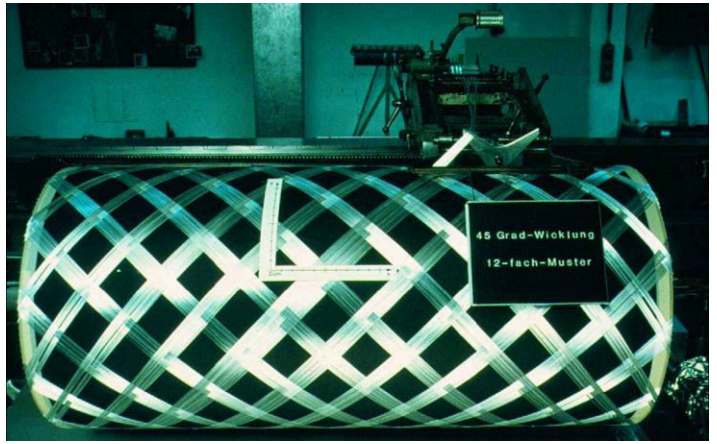


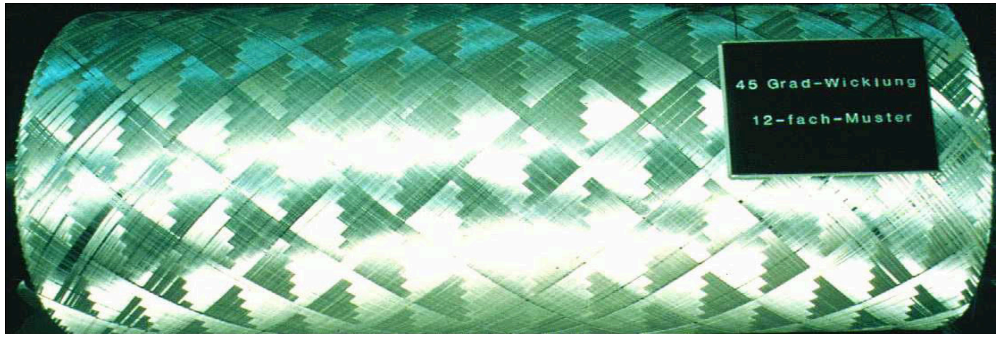
Filament winding - winding patterns











Pultrusion

Pultrusion process

- Fibres impregnate with resin
- Pull through a heated die
- Resin shrinkage reduces friction in the die
- Polyester easier to process than epoxy resin
- Tension control as in filament winding
- Moving cut-off machine ("flying cutter")

Applications

- Continuous constant cross-section profile
- Normally for thermo set (thermoplastic possible)

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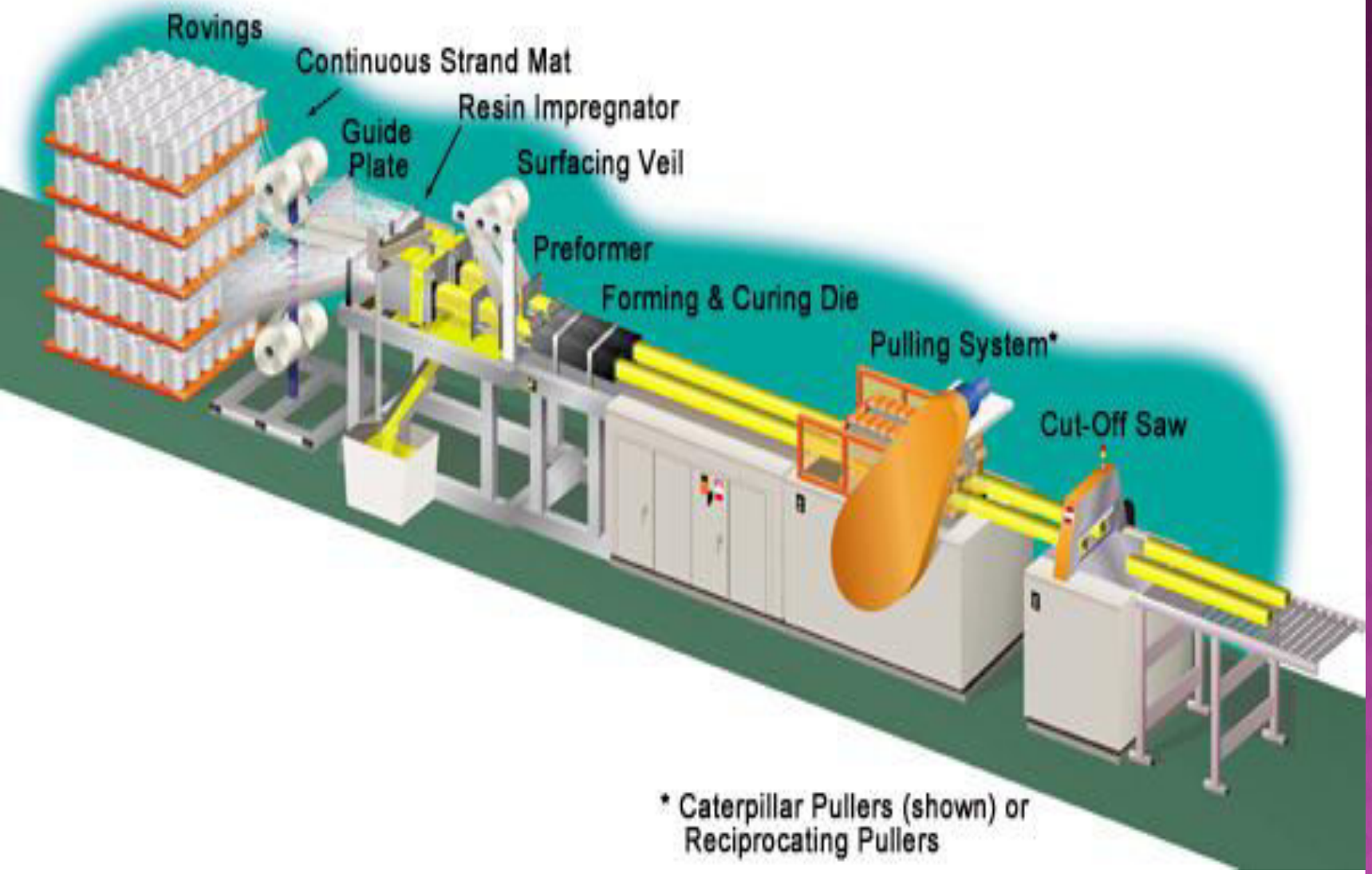
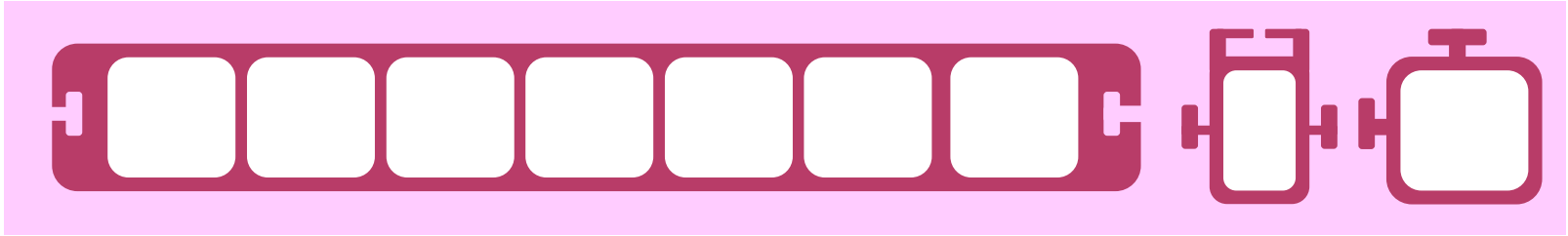
Pultrusion Manufacturing Process



Applications

- Advanced Composite Construction System
- Components: plank and connectors



- Used in Aberfeldy foot bridge and Bonds Mill Lock bridges.

Applications

- Panels – beams – gratings – ladders
- Tool handles - ski poles – kites
- Electrical insulators and enclosures
- Light poles - hand rails – roll-up doors
- 450 km of cable trays in the Channel Tunnel

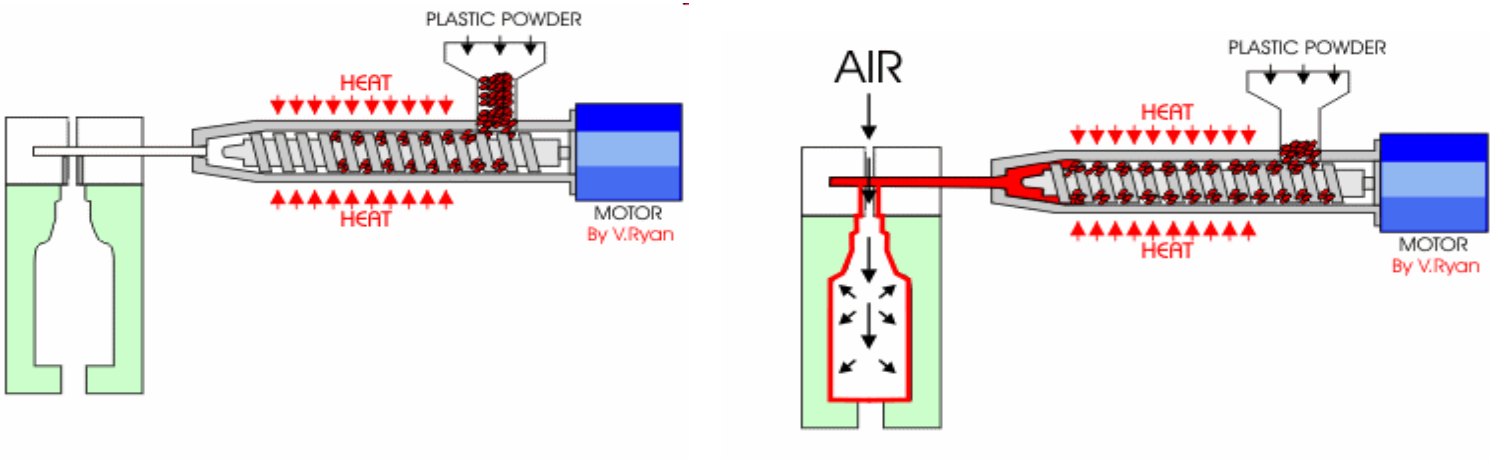
4.PROCESS FOR HOLLOW SHAPE

Blow Molding

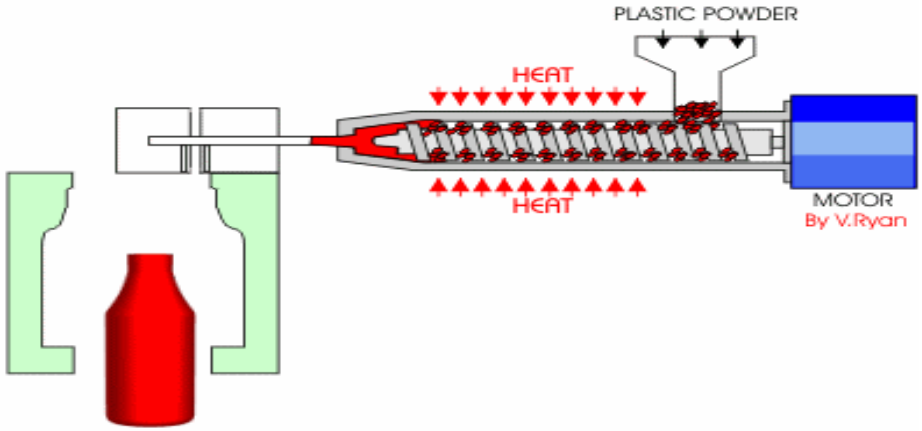
The process is similar to injection molding and extrusion.

1. The plastic is fed in granular form into a 'hopper' that stores it.
2. A large thread is turned by a motor which feeds the granules through a heated section.
3. In this heated section the granules melt and become a liquid and the liquid is fed into a mould.
4. Air is forced into the mould which forces the plastic to the sides, giving the shape of the bottle.
5. The mould is then cooled and is removed.

Blow Molding



Blow molding a shape is a common industrial process. The example shown below is of the production of a plastic bottle. The plastics normally used in this process are; polythene, PVC and polypropylene.



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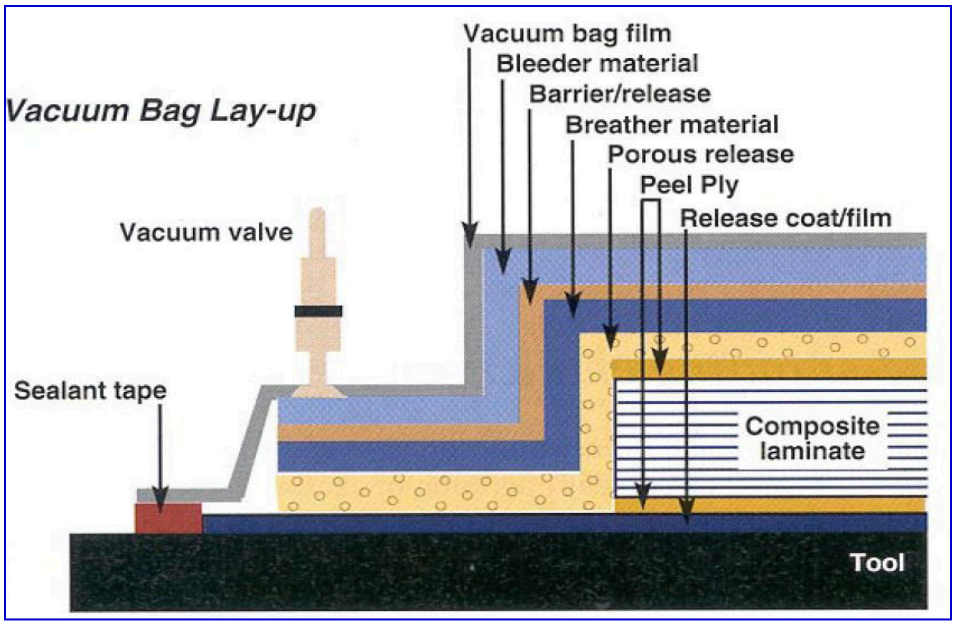
Vacuum Bagging



Autoclave Moulding

CHARACTERISTICS OF AUTOCLAVE MOULDING

- **Tool material**:

Steel, aluminum, reinforced plastics.

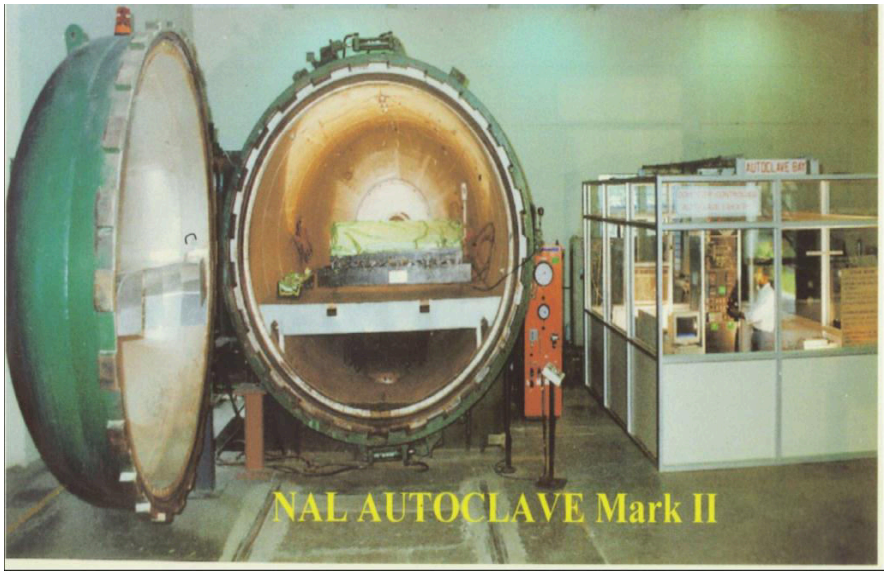
- **Curing temperature:**

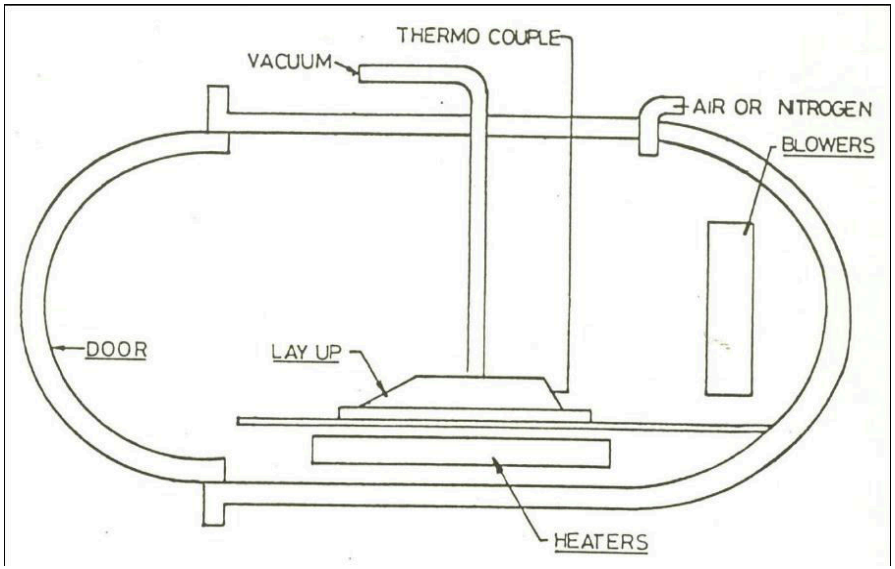
60 - 300° C

- **Curing pressure:**

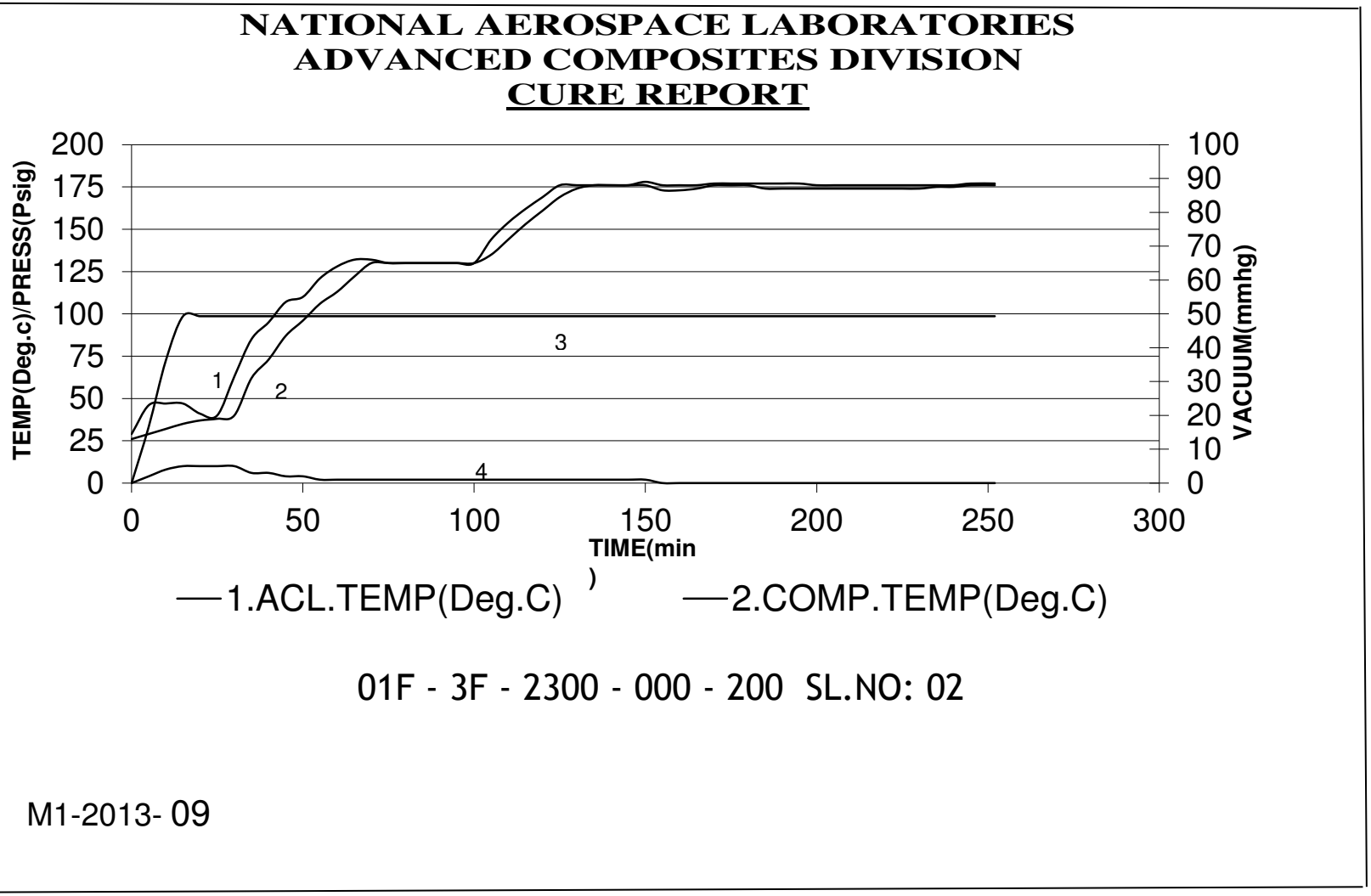
1 – 40 bar

Autoclave is a high temp.oven with temp./pressure & vacuum control.





Typical cure cycle for Carbon UD Prepreg (Hexply 914/34%/UD-160/AS4-12K/300 mm)



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OUT OF AUTOCLAVE (OOA) COMPOSITES PROCESSING TECHNIQUES

Foam cored hood

OOA curing achieves the desired fiber content and elimination of voids by placing the layup within a container such as a mold and applying vacuum, pressure, and heat by means other than an autoclave.

Types:

- Resin Transfer Molding RTM)
- Vacuum-Assisted Resin Transfer Molding (VARTM)
- Balanced pressure fluid molding.

Application:

To produce high-tech net shape aircraft components.

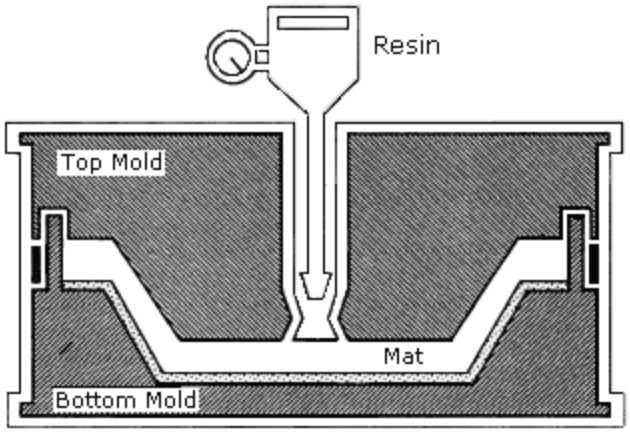
RESIN TRANSFER MOULDING (RTM)

RTM PROCESS:

- This process is used when parts **with two smooth surface** are required.
- Fibre reinforced fabric/ mat is laid by hand in to a mould and resin mixture is poured or injected in to a mould cavity.
- Then the part is cured under heat and pressure.

APPLICATIONS:

- Any shape can be produced based on mould cavity.
- Used in aerospace and electrical applications.
- Used to make floor, door and roof panels.



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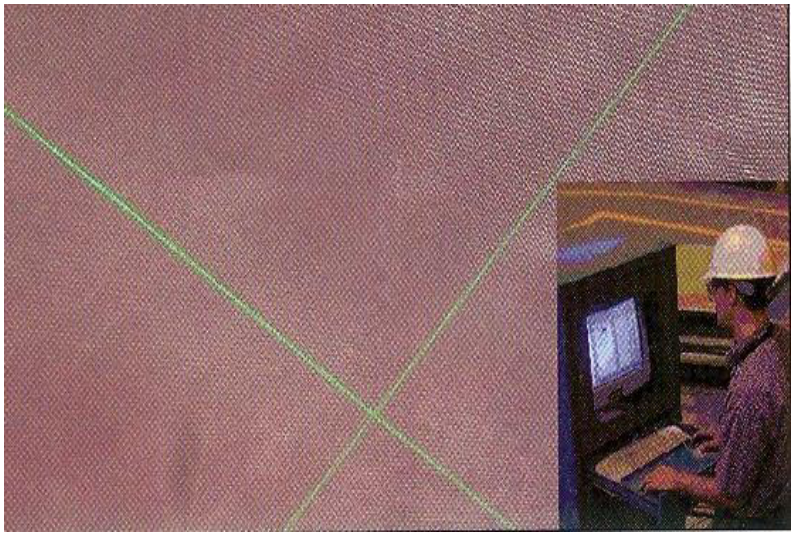
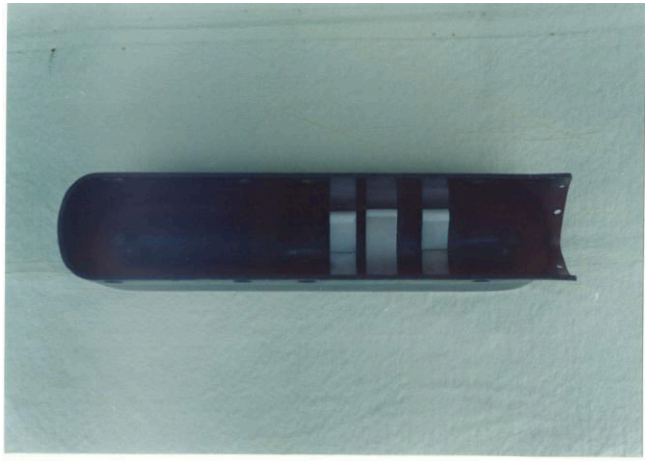
APPLICATIONS OF RIM /RTM:

Laser Projection System

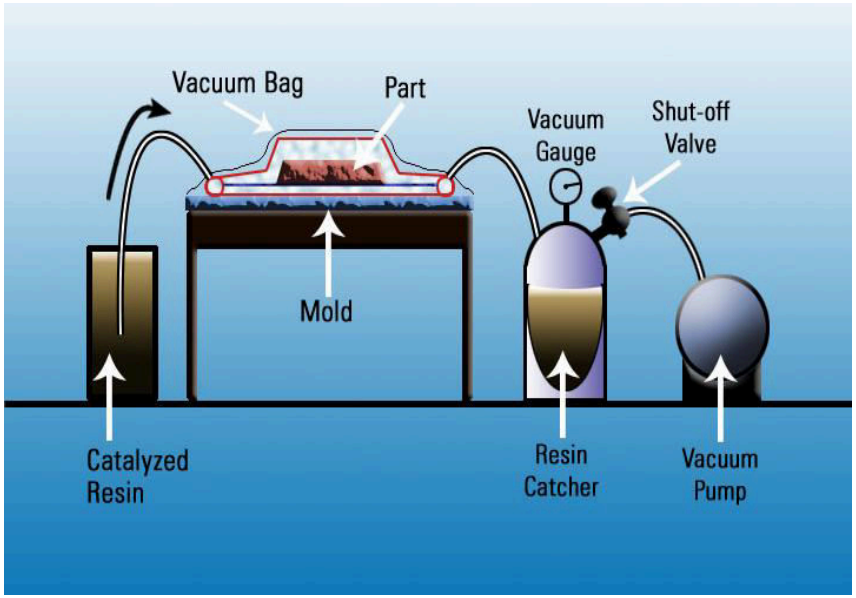




Computer Controlled Resin formulation system

RESIN INFUSION

- RTM with one tool face replaced by a flexible film or a light splash tool
- Flow of resin results only from vacuum and gravity effects
- Mould cavity varies with local pressure
- Thickness of the part depends on pressure history



Infusion setup schematic

Direct Preform process

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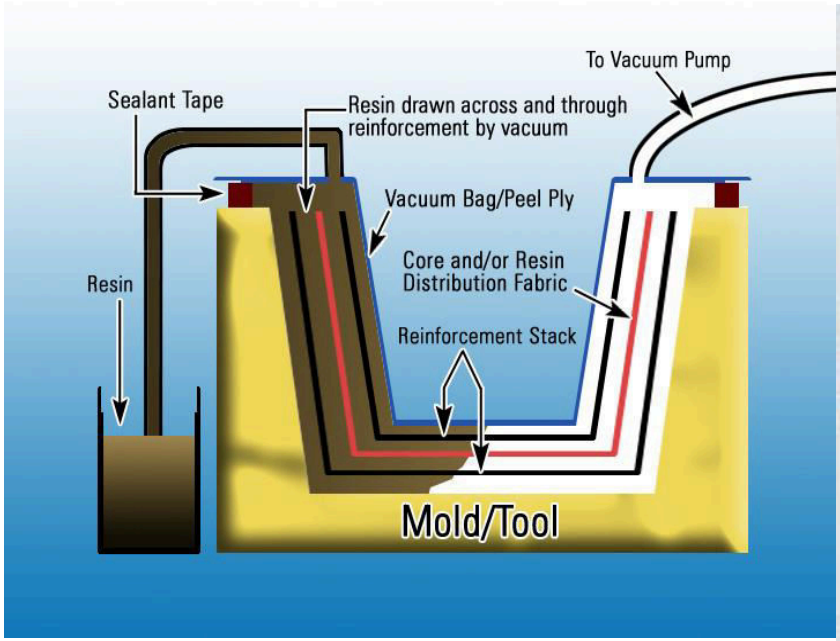
Vacuum Resin Infusion

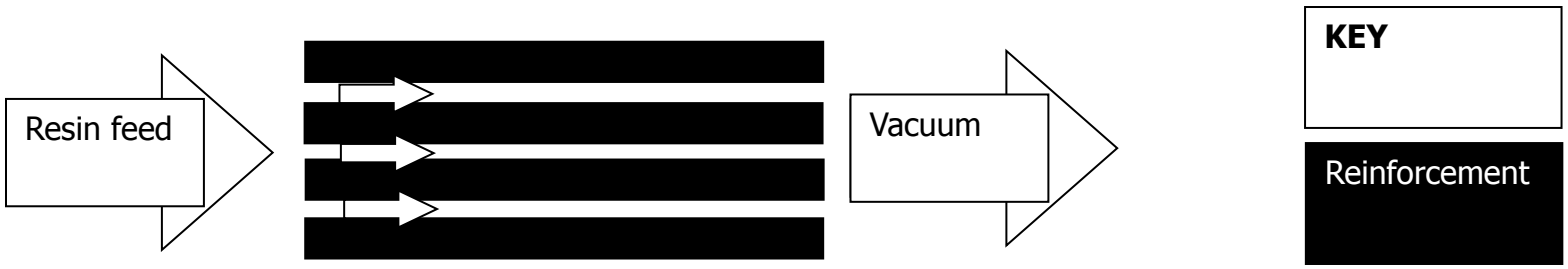


Vacuum resin infusion is similar to wet lay up except that the fabric is laid out in the mold, the part is vacuum bagged, and resin is pulled into the bag and through the fabric by a vacuum pump.

Photos courtesy Airtech Adv. Materials

Resin Infusion under Flexible Tooling (RIFT 1 of 4)

- Basic RIFT process:
  - Resin flows in the plane of the fabric between the mould and the bag



  - Slow process due to limited pressure gradient
  - Only good for
    - Low fibre volume fraction/high loft fabrics
    - Reinforcement with flow enhancement tows

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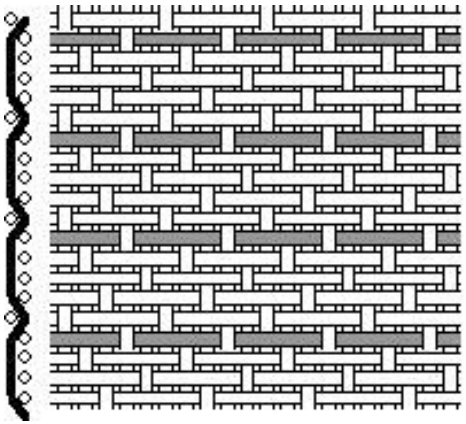
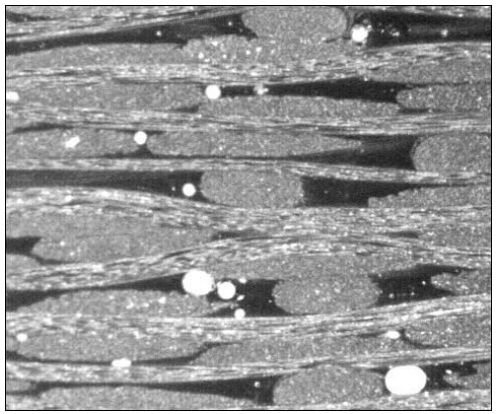
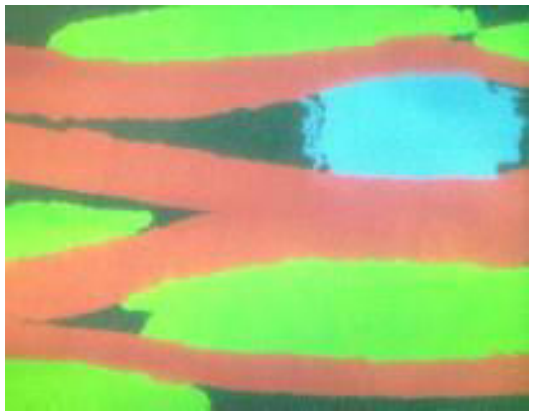
RIFT 1: Slow flow in the process

Special fabrics

- Commercial process needs flow-enhancing tows, e.g.
  - Brochier Injectex



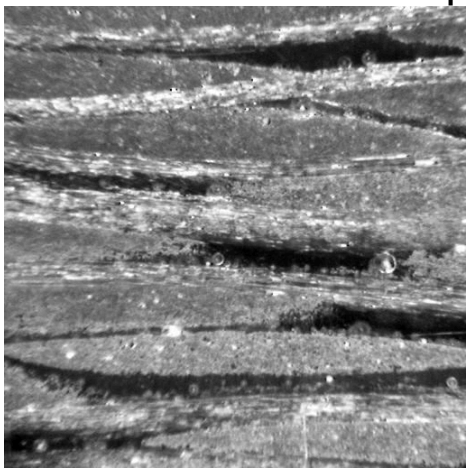




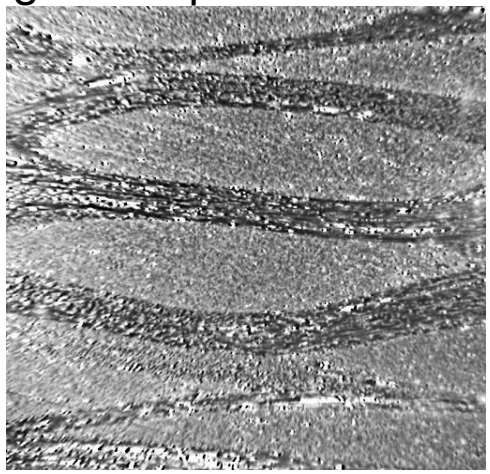
  - Carbon fabrics from Carr Reinforcements
  - Glass fabrics experimental programme with Interglas-Technologies

POTENTIAL ADVANTAGES ☺

- Large structural components can be fabricated.
- Relatively low tooling costs for high-performance components.
- Better than wet-laid components with little modification of tooling.
- Heavy fabrics more easily wetted than by hand lamination.
- Lower material costs than for prepreg and vacuum bagging.
- Higher fibre volume fraction gives improved mechanical performance.
- Minimal void content relative to hand lamination.
- More uniform microstructure than hand lay-up.
- Cored structures can be produced in a single flow process.



Hand Lamination



Resin infusion

DISADVANTAGES ☹

- Only one moulded surface
- Low resin viscosity means lower thermal and mechanical properties.
- Thinner components have lower structural moduli
- Laminate thickness dependent on flow history
- Emphasis on preparation, not on the actual moulding process.
- Sensitive to leaks (air paths) in the mould tool and the bag.
- Quality control of the resin mixing is "in-house".
- Slow resin flow through densely packed fibre
- Uneven flow could result in unimpregnated areas/scrap parts.
- Not easily implemented for honeycomb core laminates.

COMPARISON OF HAND L AY UP AND RESIN INFUSION RESINS

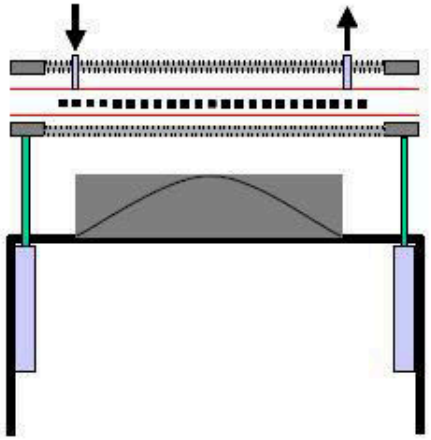
SP resin systems		hand lamination	infusion
		Ampreg 20	Prime 20
Property	*Units*		
Viscosity	mPa.s	447	188
Tg (50°C post-cure)	°C	85	86
Tensile strength	MPa	83	74

RIFT VACUUM FORMING

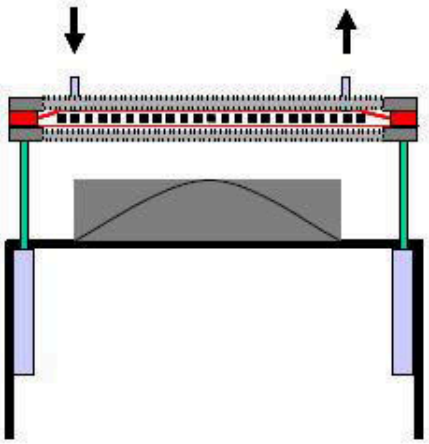
- Known as
  - DRDF: double RIFT diaphragm forming, or
  - RIDFT: resin infusion between double flexible tooling
- Dry fabric is placed between two elastomeric membranes
- Resin is infused into the fabric
- The ‘sandwich’ is vacuum-formed over the mould shape.

2m diameter CFRP sonar dome

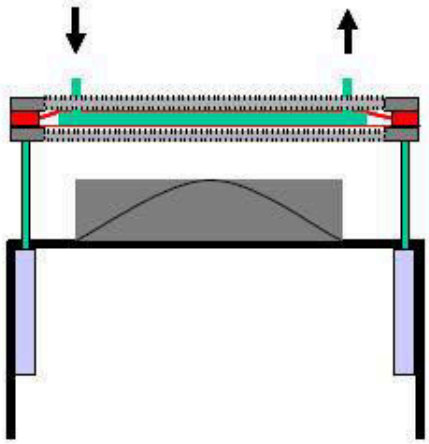
RIFT VACUUM FORMING



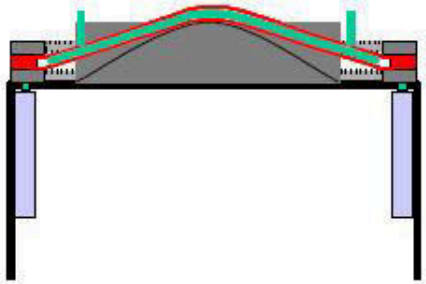
Step 1: Load fiber



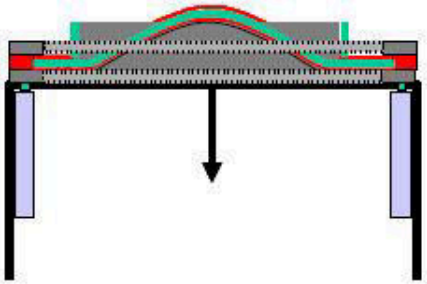
Step 2: Seal Resin Infusion Bag



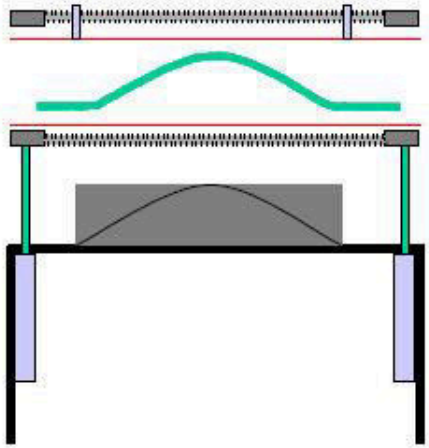
Step 3: Resin Infusion



Step 4: Seal Vacuum Chamber



Step 5: Vacuum Form Part

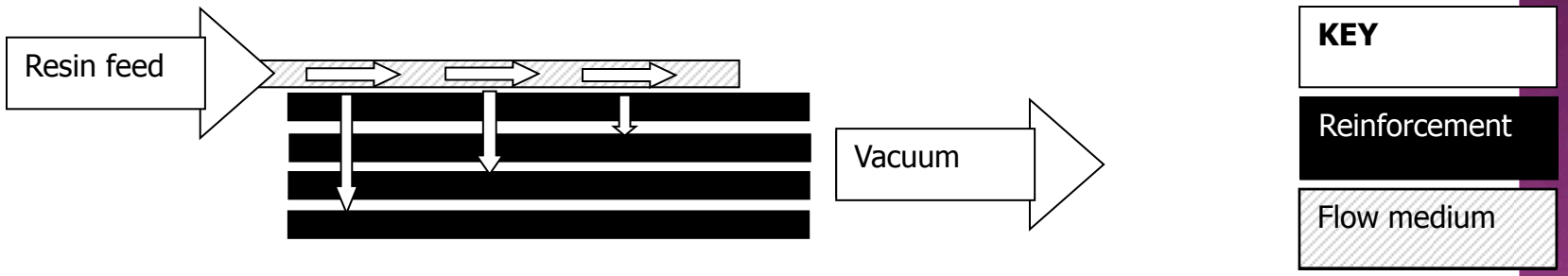


Step 6: Demold

RIDFT image from JR Thagard, PhD thesis, Florida State University, 2003.

RIFT WITH FLOW MEDIUM
RIFT 2 OF 4

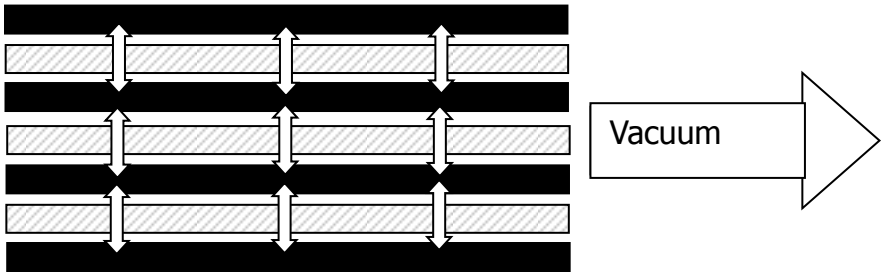
- A high permeability fabric allows resin to flood one surface followed by through-thickness flow



- Commonly referred to as either:
  - V(a)rtm
    - Vacuum (assisted) resin transfer moulding
  - Scrimp[tm]
    - Seeman composites resin infusion manufacturing process
    - Patented in the USA but prior-art exists in Europe

RESIN FILM INFUSION (RFI) RIFT 3 OF 4

- B-stage “prepreg” resin film without fibres
- Interleaved with reinforcement or grouped film layers in dry laminate
- Unlike prepreg, there are air channels within the bagged laminate



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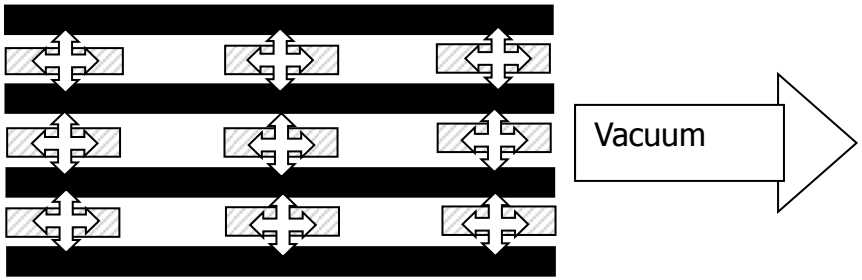
RFI (RIFT 3) FOR AEROSPACE

- T-beams, aileron skin, swaged wing rib, three-bay box
  - Kruckenberg *et al* , SAMPE J, 2001
- Fuselage skin panel for the boeing 767 aircraft was moulded as a demonstrator with integral stiffeners
  - Cytec 5250-4RTM bismaleimide resin (100 mpa.S at 100°C)
  - 880 x 780 mm woven 5-axis 3-D fabric preform
  - Uchida *et al* , SAMPE J, 2001
- Fuselage panels in TANGO technology application to the near-term business goals and objectives of the aerospace industry
  - Skins will be non-crimp fabric preforms
  - Integrated stringers to be triaxial braids with unidirectional fibres
  - Fiedler *et al*, SAMPE J, 2003

“Semi-preg” infusion
RIFT 4 of 4

- Fabric partially pre-impregnated with resin



- Commercial systems include
  - Cytec carboform
    - Resin impregnated random mat between the two fabric layers
  - Hexcel composites hexfit^{tm}
    - Film of prepreg resin combined with dry reinforcements
  - SP systems SPRINT®: SP resin infusion new technology
    - Resin between two fabric layers
  - Umeco (ACG) ZPREG
    - Resin stripes on one side of fabric

SUMMARY

- Reviewed the four major variants of the resin infusion under flexible tooling process.
- Considered the application of these techniques to the manufacture of large composite structures.
- Recommend this route for the manufacture of large composite structures.

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REVIEW ON COMPOSITE PRODUCT DEVP.TECHNIQUES

PROCESS	ADVANTAGES	DISADVANTAGES
Hand Lay-up Process	1.Simple & Fairly cheap. 2.Inexpensive Tooling. 3.Arbitary Stacking sequence can be used.	1.Low Production Process. 2.Low strength & Stiffness. 3.Quality is greatly dependent on operator skill.
Spray Lay-up Process	1.Much faster 2.Better quality parts. 3.Less operator dependent.	1.Resin flow control is difficult 2.High tooling cost.
Autoclave/pressure Bag moulding.	1.The component is of uniform quality. 2.Easy process control.	1.High initial investment cost. 2.Need,well trained personnel 3.Part size is based on autoclave dimension.
Sheet molding compound (SMC) / Bulk molding compound (BMC)	1.Automated Process. 2.Moulding are smooth on all surfaces and show almost no 'Fibre Structure'.	1.Difficult to make very thick Components 2.Mould design critical.

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Comparison of Various Composite Processing Technologies

PROCESS	ADVANTAGES	DISADVANTAGES
Filament winding.	1.Flexible Process . 2.Labour cost is less 3.High quality of Structural Parts.	1.High initial investment cost. 2.Need,well trained personnel 3.Limitation on structural geometries.
Pultrusion process.	1.High production rate. 2.Good & Uniform Mechanical Properties. 3.Exchange of die is easy.	1.High initial investment. 2.Special resins are required. 3.Suitable for Constant cross-section parts only.
RTM / RIM	1.Complex shapes can be produced with good surface finish. 2.Near net shape parts can be made.	1.Tooling Complexity 2.Difficult to control resin flow. 3.Wetting the preform is difficult. 4.Full automation process.

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APPLICATION OF POLYMER MATRIX COMPOSITES IN AIRCRAFT STRUCTURES

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Composite parts in LCA (Tejas) Aircraft

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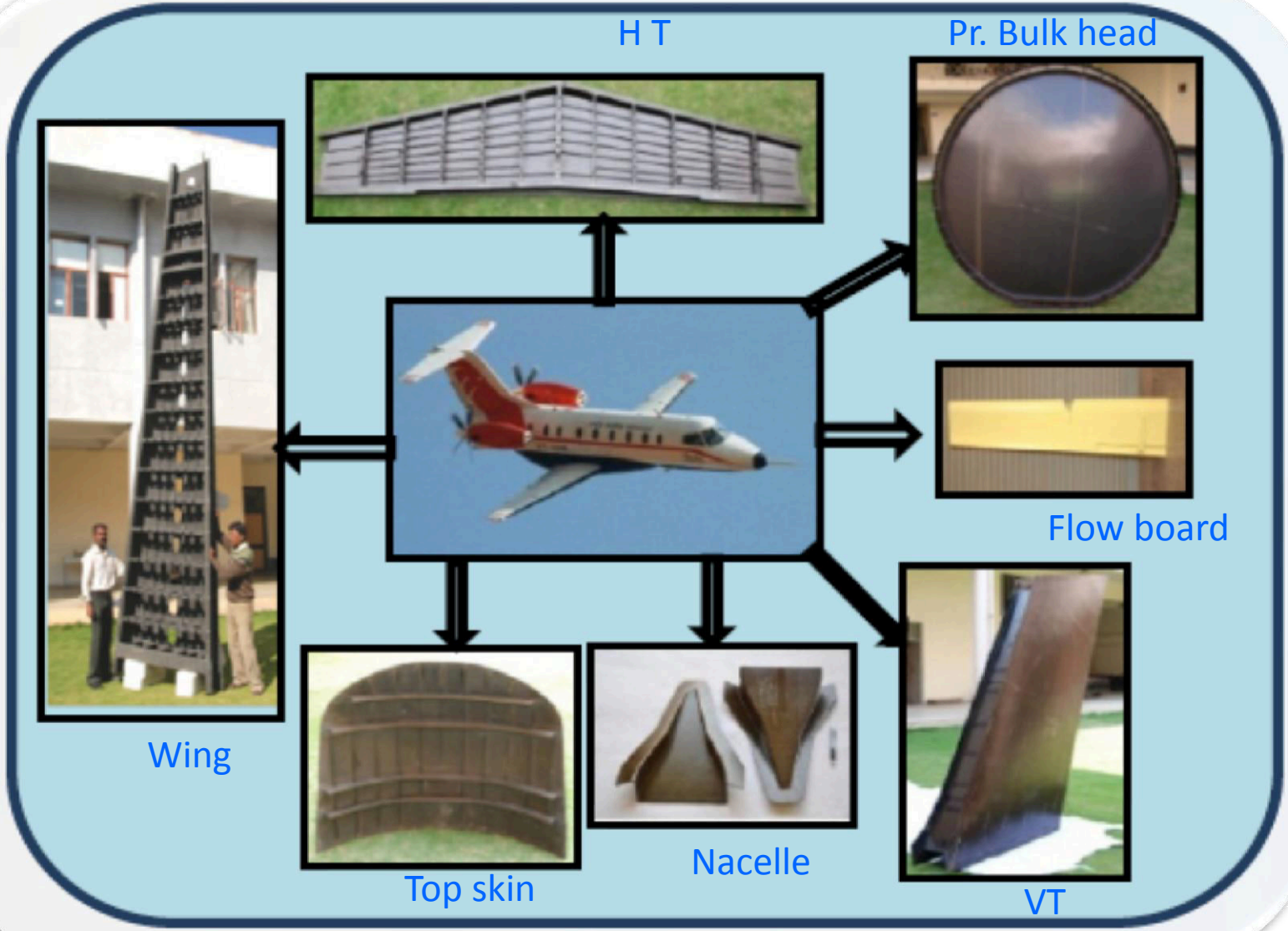
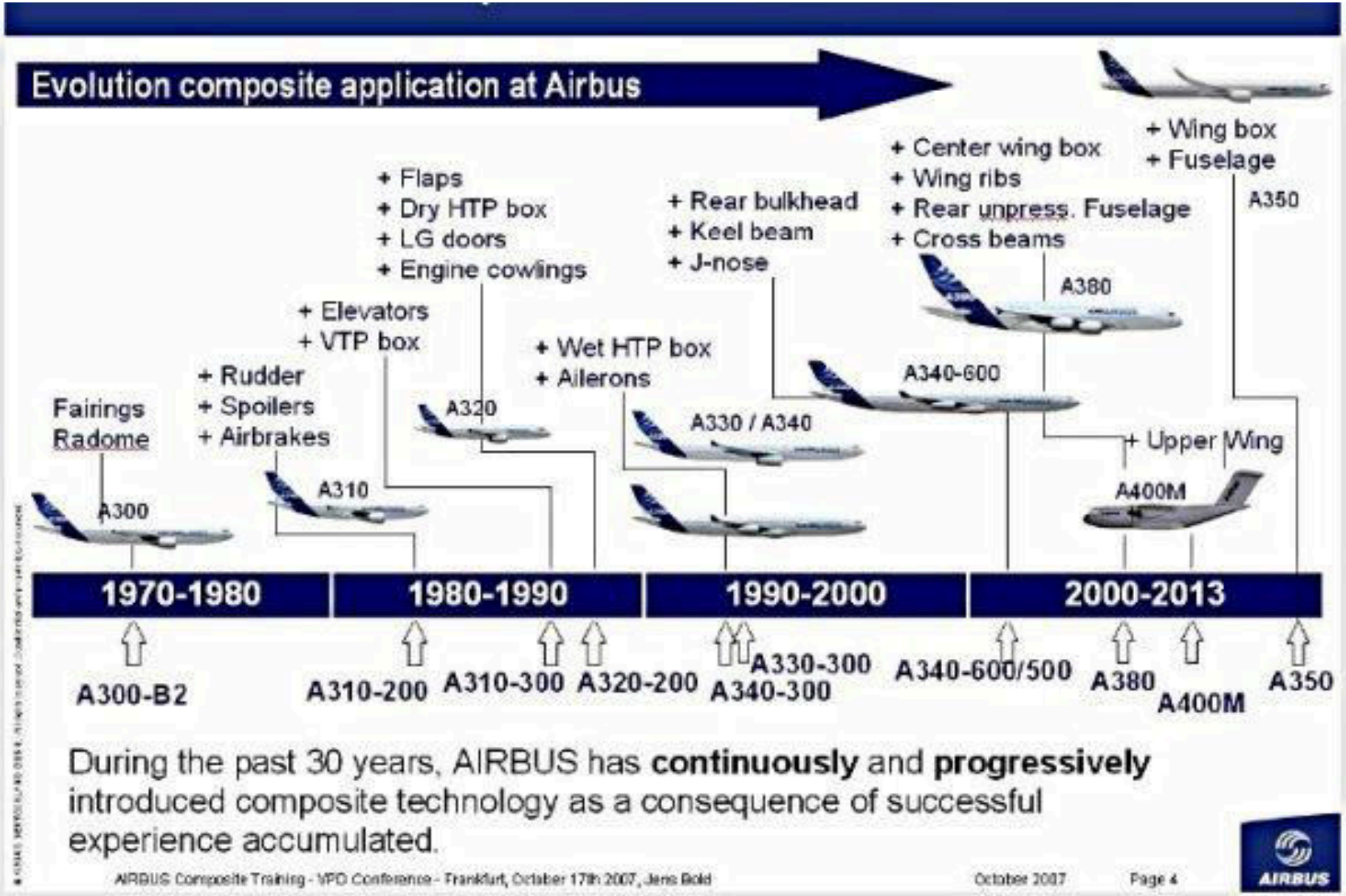
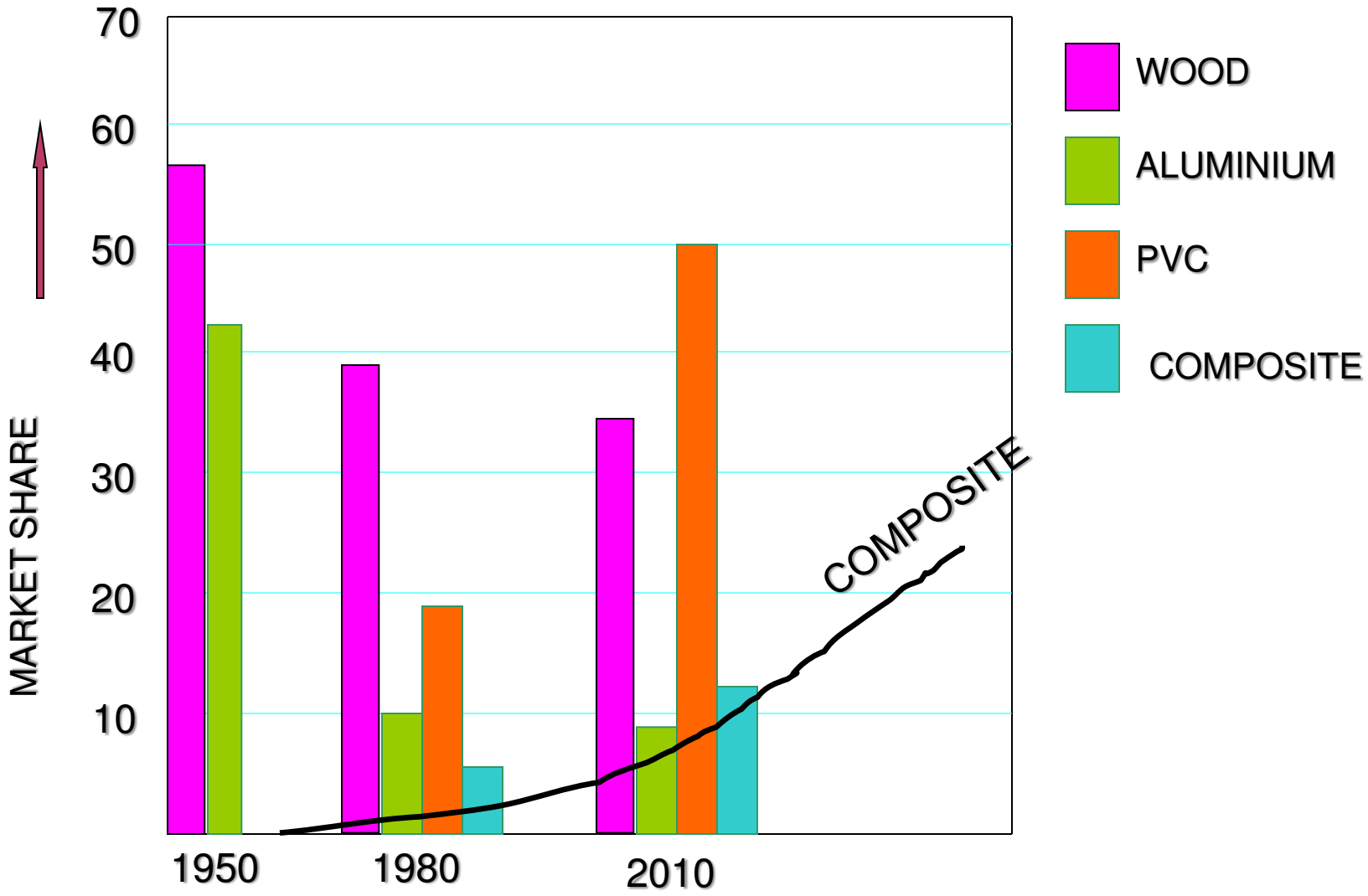
Composite parts in NAL's SARAS Aircraft



Evolution composite application at Airbus



Future of Composites



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Concluding Remarks

- Composites are plastic materials . They are superior to metals as they have high specific strength and high stiffness, corrosion resistance.
- **They are anisotropic materials.**
- As they are directionally sensitive materials, we can tailor the fibers to get the desired strength or stiffness. Hence composites are called “Designer made “ materials.
- **Conventional composite processing techniques for aircraft parts use structural grade pre-pregs and adhesives under vacuum and high temperature curing.**
- Generally depending on application, PMC processing methods will be opted.
- **For fighter aircraft large composite structures, autoclave molding is recommended in view of service temp. requirements**
- Commonly used OOA processes are RTM, VARTM etc.

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Concluding Remarks

- Bonded joints preferred over Bolted joints. Generally in bonded repairs one has to design the patch to match the strength and stiffness of the material
- **Complex structures can be produced using advanced composites by autoclave moulding.**
- This saved 10% of weight and 20 % cost over conventional composite riveted structure
- **Demonstrated the possibility of secondary bonding for closed structure by intelligent tooling.**
- Successful operation of Rudder in 10 flying aircraft vindicates the secondary bonding technology.
- **Selection of a Composite Product Devp. Tech for PMC processing depends on a host of variables like Service temp. of the part, resins, cost ,etc**

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Summary

- **PMC processing depends on:**
  - ✓ **Part functionality**
  - ✓ **Tg**
  - ✓ **Cost**
  - ✓ **Processing Time**
  - ✓ **Resin**
- Hence Composite product development technology is an art with lot of science content & hence it is charming.
- **Recent trend in composite processing technique for aerospace depends on cost & volume of production.**
- As a product development engineer, one has to study the state of art processing techniques used worldwide & select an optimal process, be it autoclave based or OOA.

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5) Proceedings of "Workshop on repair technology for composite structures" Vol-1 (theory) NAL Doc.No.PR-AC-01-01, 2001
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ANY QUESTIONS, WELCOME !